The Effects of Controlled Feeding of a High-Forage or High-Concentrate Ration on Heifer Growth and First-Lactation Milk Production¹

G. I. Zanton and A. J. Heinrichs²

Department of Dairy and Animal Science, The Pennsylvania State University, University Park 16802

ABSTRACT

The objective of this experiment was to evaluate growth and first-lactation milk production in dairy heifers fed a high-forage (HF) or high-concentrate (HC) ration for similar levels of average daily gain (ADG) before puberty. Responses in weight and structural gains were determined on 41 Holstein heifers fed diets containing the same ingredients but formulated in different proportions to give 2 treatment rations of 75% forage or 75% concentrate. The feeding period lasted 245 d, and individual animal dry matter intake was controlled to maintain constant ADG between diets. Puberty was assessed, and first-lactation milk production was evaluated through 150 d. Average dry matter intakes required to achieve desired levels of gain were 5.96 HF and 5.32 HC kg/d ($SE \pm 0.12$), and the associated feed efficiency (kg of ADG/kg of dry matter intake) was 0.142 HF and 0.156 HC ($SE \pm 0.003$) over the experimental growth period. Throughout the feeding period, ADG was not affected by treatment (0.828 HF vs. 0.827 HC; $SE \pm 0.010$ kg/d). Gains in structural measurements were not affected by treatment with the exception of paunch girth, which increased faster in HC-fed heifers. Body weight at puberty (293 HF vs. 287 HC; $SE \pm 7$ kg) and experimental ADG prior to puberty (0.837 HF vs. 0.837 HC; $SE \pm 0.009$ kg/d) were not different between rations. Milk and component production were numerically greater for heifers fed HC prior to puberty, although only fat-corrected milk and fat production were significant. From the results of this experiment we conclude that, compared with heifers fed HF for equal ADG, feeding dairy heifers HC before puberty did not affect most structural growth characteristics or puberty attainment and allowed equal or improved 150-d milk and component production. Controlled feeding of HC during the rearing period may

allow for improved growth efficiency for dairy heifers while maintaining future productivity.

Key words: heifer, forage to concentrate ratio, growth, milk production

INTRODUCTION

The overall feed efficiency (**FE**) with which dairy heifers are reared is quite low. Although this arises from many different sources, a large share of this inefficiency relates to the large proportion of feed required for maintenance purposes and the relatively inefficient use of feed for growth. For instance, the proportion of net energy intake that is retained for growth is considerably lower than the proportion which is expended for maintenance (Lofgreen and Garrett, 1968). However, the absolute amount of energy required for maintenance is several times greater than it is for growth (NRC, 2001). An analogous situation exists for nearly all nutrients required by dairy heifers. Additionally, none of the investments made during the rearing period has the potential to generate revenue until lactation commences.

Reducing the length of the growing period by decreasing age at first calving below recommendations (22 to 24 mo; Ettema and Santos, 2004) could shorten the time between expenditure and revenue generation and reduce the costs associated with the nonproductive period. This could be accomplished by increasing prepubertal ADG, which would subsequently result in a lower age at first breeding and presumably a lower age at first calving. Although this strategy would ultimately lead to an earlier return on investment, increased prepubertal ADG has been demonstrated to have a negative impact on mammary parenchyma cell numbers (Sejrsen et al., 1982; Meyer et al., 2006) and first-lactation milk yield (Van Amburgh et al., 1998; Lammers et al., 1999; Radcliff et al., 2000). Determining a strategy to accelerate the growth of dairy heifers without subsequently reducing production should continue to be investigated. Even if a methodology to accelerate growth without reducing lactation performance could be implemented, the comparatively low efficiency of heifer rearing remains, albeit for a shorter duration of time.

Received January 21, 2007.

Accepted April 2, 2007.

¹This research is a component of NC-1119; Management Systems to Improve the Economic and Environmental Sustainability of Dairy Enterprises.

²Corresponding author: ajh@psu.edu

It has been known for some time that diets containing high proportions of concentrate feedstuffs are utilized with greater efficiency than those containing high proportions of forages (Blaxter and Wainman, 1964; Garrett, 1979). Several experiments have offered dairy heifers high-concentrate (**HC**) diets for ad libitum consumption, which has led to reduced first-lactation milk production (Swanson, 1960; Radcliff et al., 2000). However, other experiments have demonstrated that if HC diets are restricted so that ADG is comparable to a high-forage (**HF**) control diet, mammary development and first-lactation milk production do not differ between groups (Hof and Lenaers, 1984; Sejrsen and Foldager, 1992; Carson et al., 2000). Despite these results, dairy heifers commonly receive diets in which the majority of nutrients come from forages instead of concentrates. Therefore, the objective of this experiment was to evaluate growth and first-lactation milk production in dairy heifers fed HF or HC rations for similar levels of prepubertal ADG.

MATERIALS AND METHODS

Heifer Management, Treatments, and Measurements

To accomplish this objective, 42 Holstein dairy heifers from The Pennsylvania State University dairy herd were enrolled in the experiment in groups of 4 to 8 after reaching a BW of 125 kg (117 ± 2 d of age). Heifers were blocked by previous calf experimental treatment (Kehoe et al., 2007; this experiment was completed for a minimum of 4 wk prior to initiation of the current experiment) and randomly assigned to treatment rations. For 35 d heifers were adapted to differing levels of forage by incrementally increasing or decreasing the amount of forage and use of Calan feeding doors (American Calan, Northwood, NH). Heifers were housed in an open-sided barn with natural ventilation and continuous access to fresh water. Pens were sand-bedded and housed groups of 6 or 9 heifers receiving the same treatment. Heifers were not housed with heifers receiving the opposite treatment because of the anticipated differences in time required to complete a meal and the potential aggression directed toward those heifers with access to feed. All procedures involving animals were approved by The Pennsylvania State University Institutional Animal Care and Use Committee.

The treatment rations were formulated on a quantity basis to meet or exceed the NRC (2001) nutrient recommendations for a 150-kg Holstein heifer gaining 0.800 kg/d and for all macronutrients to be equal between the rations (Table 1). The HF control diet was formulated to contain 75% forage and 25% concentrate, and the HC diet was formulated to contain 25% forage and 75% concentrate. Heifers were individually fed a TMR twice

Table 1. Mean treatment ration formulation and composition

Ingredient, % of DM	Diet	
	High forage	High concentrate
Grass silage	38.37	12.66
Corn silage	36.76	12.18
Cracked corn	8.70	49.12
Soybean meal	7.60	7.34
Cottonseed hulls	5.06	12.31
Urea	0.17	1.09
Sodium bicarbonate	0.85	0.87
Corn distillers grains with solubles	1.60	2.01
Vitamins A, D, E ¹	0.02	0.02
Potassium magnesium sulfate	0.00	0.14
Se, 0.06%	0.04	0.04
Salt	0.39	0.34
Magnesium oxide	0.00	0.07
Limestone	0.39	0.85
TM Premix ²	0.04	0.03
Potassium chloride	0.00	0.93
Composition ³		
ME, Mcal/kg of DM	2.33	2.48
CP, %	11.72	14.98
NDF, %	45.40	29.78

¹Vitamins A, D, E contained 30,000 kIU of vitamin A/kg, 7,250 kIU of vitamin D/kg, and 180 kIU of vitamin E/kg.

²TM Premix contained Ca, 0.57%; S, 15.75%; Cu, 40,816 ppm; Fe, 10,204 ppm; Mn, 122,450 ppm; Zn, 122,450 mg/kg.

³Calculated according to the NRC (2001) based on individual feed ingredients and forage analysis.

daily at 12-h intervals (0800 and 2000 h). Heifers were fed these rations for 245 d in an attempt to encompass and isolate the prepubertal allometric mammary growth phase (Sinha and Tucker, 1969). An important consideration in this experiment was to maintain similar ADG throughout the prepubertal phase so that effects of differing levels of forage and concentrate could be determined independently from alterations in prepubertal ADG. Although the energy density of the 2 rations differed considerably, ADG was controlled by controlling the amount of each ration offered. Heifers were weighed on 2 consecutive days, 2 h prior to the morning feeding (0600 h), at weekly intervals; from the mean of these weights, the amount of feed offered in the subsequent week was adjusted to maintain the desired ADG. Concurrent with weekly weighing, several structural measurements also were recorded, including withers height, body length (point of the shoulders to the ischium), heart girth, paunch girth, and hip width (Brody, 1945). At the conclusion of the experimental period, heifers were transitioned onto a common HF diet (66% grass silage, 20% corn silage) that was group-fed until animals entered the precalving transition group between 30 and 60 d prior to calving. After the experimental feeding period was complete, heifers from each treatment were managed as a single group in a manner consistent with other heifers on the farm.

Reproduction

The onset of puberty was monitored beginning at 200 kg of BW by measuring serum concentrations of progesterone. Blood samples were collected by jugular venipuncture twice per week using 10-mL serum Vacutainer tubes (Becton Dickinson Systems, Franklin Lakes, NJ) at intervals of approximately 3.5 d. Serum samples were allowed to separate for a minimum of 2 h and then centrifuged at $4,000 \times g$ at 22°C for 15 min. Serum was aspirated and stored at -20°C until analysis for progesterone. Progesterone was analyzed using solid-phase RIA kits (Coat-A-Count Progesterone, DPC, Los Angeles, CA). Heifers were considered pubertal when at least 2 consecutive samples possessed a progesterone concentration >1 ng/mL. Additionally, estrus detection was performed for 30 min/d as a further indicator of puberty.

Heifers were considered eligible for first breeding at 350 kg and 13 mo. In an effort to obtain a first calving age within the recommended range of 22 to 24 mo, heifers not inseminated prior to 13.5 mo of age were subjected to an estrus synchronization program including controlled-release intravaginal progesterone (Eazi-Breed CIDR, InterAg, Hamilton, New Zealand) and an injection of prostaglandin (Lutalyse, Pharmacia & Upjohn, Kalamazoo, MI). This protocol also was used for services subsequent to an open pregnancy diagnosis. The number of services required per pregnancy was recorded for comparative purposes, and heifers requiring >4 services were eliminated from the experiment ($n = 2/\text{treatment}$).

Lactation

Cows calved in individual pens, were milked, and were then transferred to a tie-stall barn (stall dimensions 132×183 cm) where the animals were transitioned to the lactation ration and monitored for postparturient problems. After approximately 1 mo, cows were transferred to a free-stall, sand-bedded barn with other first-lactation cows. The lactation ration was formulated as a TMR designed to meet nutrient requirements based on level of milk production according to the NRC (2001). Feeding occurred once per day at approximately 0700 h, and cows were allowed ad libitum access to feed and water. Cows were administered bST (Posilac, Monsanto Co., St. Louis, MO) biweekly beginning at 63 DIM.

Cows were milked twice daily at 0500 and 1700 h in a double-10 herringbone milking parlor equipped with the Affarm system (S.A.E. Afikim, Kibbutz Afikim, Israel; US distributor: Germania Dairy Automation, Waunakee, WI). Milk yield was recorded for individual animals at each milking, and cows were weighed upon

exiting the parlor. Monthly, at 2 consecutive milkings, milk samples were collected and analyzed for fat and protein (Dairy One DHIA, Ithaca, NY). Mature equivalent 305-d production values were calculated by DHIA procedures and are reported based on the first 154 DIM.

Calculations and Statistics

Because heifers were individually fed and intake and ADG for each animal were known, the individual heifer was considered the experimental unit. The previous experiment treatment blocking variable was retained in all cases, except where noted below, as a penalty against complete randomization. As mentioned previously, heifers were grouped in pens with other animals receiving the same treatment. For this reason, a fixed covariate effect was included for pen nested within treatment to account for potential pen-to-pen effects.

Any response for which there was one observation per animal (age at puberty, BW at calving, etc.) was analyzed according to a randomized complete block design including previous treatment and pen within treatment as covariates in PROC MIXED (SAS Institute, 2006). Repeated measurements during lactation were analyzed as in the above model, expanded to include the fixed effect of week and the treatment by week interaction. Intercept and week within cow within pen within treatment were included as random effects as variance components, and the correlation between residuals attributable to repeated measures was modeled using the first-order autoregressive covariance structure.

For weight and structural measurement gain, the following linear covariate mixed effects model was fit using PROC MIXED of SAS:

$$Y_{ijkh} = \{B_0 + B_0T_i + B_0P_j + B_0G_{k(i)} + b_{0h[k(i)]}\} \quad [1] \\ + \{B_1 + B_1T_i + B_1P_j + B_1G_{k(i)} + b_{1h[k(i)]}\} \times t + e_{ijkh},$$

where Y_{ijkh} is a continuous, dependent response variable; B_0 is the overall intercept across treatment, previous treatment, pen grouping, and heifer; B_0T_i is a fixed effect of the i th treatment on the intercept ($i = 1, 2$); B_0P_j is a fixed effect of the j th previous treatment on the intercept ($j = 1, \dots, 5$); $B_0G_{k(i)}$ is a fixed effect of the k th pen grouping within the i th treatment on the intercept ($k = 1, 2, 3$); $b_{0h[k(i)]}$ is a random effect of the h th heifer within the k th pen within the i th treatment on the intercept ($h = 20$); B_1 is the overall slope (daily gain) across treatment, previous treatment, pen grouping, and heifer; B_1T_i is a fixed effect of the i th treatment on the slope ($i = 1, 2$); B_1P_j is a fixed effect of the j th previous treatment on the slope ($j = 1, \dots, 5$); $B_1G_{k(i)}$ is a fixed effect of the k th pen grouping within the i th

treatment on the slope ($k = 1, 2, 3$); $b_{1h[k(i)]}$ is a random effect of the h th heifer within the k th pen within the i th treatment on the slope ($h = 20$); and t is the continuous effect of time on trial in days after 35 d of adaptation; with

$$\begin{bmatrix} b_{oh(k(i))} \\ b_{1h(k(i))} \end{bmatrix} \sim N \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{bmatrix} \sigma_{b_0}^2 & \sigma_{b_0 b_1} \\ \sigma_{b_1 b_0} & \sigma_{b_1}^2 \end{bmatrix} \right],$$

and e_{ijkh} is the residual error.

Error correlation within heifers across days on trial was modeled using the first-order autoregressive covariance structure because of being repeated measures on the same animal across time. This procedure makes use of all measurements taken, does not rely solely on the initial and final measurements, and allows each covariate (treatment, previous treatment, and pen and the random effect of heifer) to be estimated simultaneously. The model was restrained to linear effects, although quadratic or greater effects were significant for some measurements. It must be noted, however, that in the regression equation for BW, the quadratic, nonlinear component was rejected ($P > 0.40$), indicating that during the time frame of this experiment, heifers grew at an approximately linear rate.

To overcome difficulties associated with the nonlinearity of the structural measurements, allometric equations were used relating the structural response of interest to BW. To assess effects that dietary treatments had on growth of structural characteristics relative to growth of the whole body, an allometric, nonlinear model was fit in the NLMIXED procedure of SAS:

$$Y_{ih} = [B + BT_i + b_{h(i)}] \times BW^{[K+KT_i+k_{h(i)}]} + e_{ih},$$

where Y_{ih} is the continuous, dependent response variable; B is a scaling coefficient of the equation across treatment and heifer; BT_i is a fixed effect of the i th treatment on the scaling coefficient ($i = 1, 2$); $b_{h(i)}$ is a random effect of the h th heifer within the i th treatment on the scaling coefficient ($h = 20$); K is the overall allometric growth coefficient across treatment and heifer; KT_i is a fixed effect of the i th treatment on the allometric growth coefficient ($i = 1, 2$); and $k_{h(i)}$ is a random effect of the h th heifer within the i th treatment on the allometric growth coefficient ($h = 20$); with

$$\begin{bmatrix} b_{h(t)} \\ b_{h(i)} \end{bmatrix} \sim N \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{bmatrix} \sigma_b^2 & \sigma_{bl} \\ \sigma_{kb} & \sigma_k^2 \end{bmatrix} \right],$$

and e_{ih} is the residual error, $\sim N(0, \sigma_e^2)$.

This is the typical expression for the allometric growth equation (Huxley, 1932) extended to account for variation arising from the fixed effect of treatment and the random effect of heifer in a manner similar to that used for the Gompertz growth function by Wang and Zuidhof (2004). This analysis is valuable in determining effects that treatment has on the growth of measured structural parameters relative to growth of the whole body and allows treatment effects and random individual heifer effects to be estimated simultaneously. Being nonlinear, this analysis is also preferred to quadratic or higher order polynomial equations in accounting for nonlinearity of growth curves, which suffer from high levels of multicollinearity between the parameter estimates. The covariate parameters included in previous models were originally included in this analysis as well; however, they were highly nonsignificant ($P > 0.90$) and made it difficult fitting the complex nonlinear mixed model and were thus excluded from this analysis.

The assumption of normality was assessed using the normal probability plot correlation coefficient test (Filliben, 1975). Homoskedasticity of residuals and the presence of outliers were evaluated by assessing the Studentized residual plot, with outliers defined as Studentized residuals greater than 3 standard deviations. Figures for structural growth measurements present the dependent variable of interest adjusted for random effects according to St-Pierre (2001). This presents graphically only the variation attributable to treatments, while still accounting for random effects in fitting the model. Values presented in Tables 2 and 3 are regression coefficients fit using models 1 and 2; otherwise least squares means are presented. Differences were considered statistically significant where $P < 0.05$ and tending toward significance where $P < 0.10$.

RESULTS AND DISCUSSION

General

Heifers in this experiment were generally healthy throughout the feeding trial, and all animals completed this portion of the trial except one (HC); which was removed for reasons unrelated to treatment. Eight animals of the original 42 did not complete 150 d of lactation: 4 did not conceive by 4 inseminations (2 HC, 2 HF); 1 was diagnosed with chronic pneumonia and was culled (HF); 1 had extreme difficulty calving and was paralyzed (HF); and 1 died after calving (HC). Thus, the results for animal growth had 21 HF and 20 HC heifers in the analysis. Reproductive results are presented only for those heifers completing 150 d of lactation for consistency with lactation performance results ($n = 17$ HF and 17 HC).

Table 2. Growth responses for Holstein heifers fed a high-forage (HF) or high-concentrate (HC) diet for similar ADG before puberty¹

Item	Initial size ²				Daily gain ³			
	HF	HC	SE	P ⁴	HF	HC	SE	P ⁴
BW, kg	139	141	5	0.801	0.828	0.827	0.010	0.943
Withers height, cm	101	103	1	0.083	0.113	0.114	0.002	0.665
Heart girth, cm	117	118	1	0.914	0.210	0.213	0.003	0.440
Paunch girth, cm	149	141	2	0.004	0.190	0.247	0.009	<0.001
Length, cm	108	111	1	0.082	0.157	0.160	0.003	0.653
Hip width, cm	27	27	1	0.576	0.060	0.061	0.001	0.526

¹n = 21 for HF and n = 20 for HC, those that completed the feeding trial.

²Initial size values were calculated as the intercept of the regression equation, where Y = variable of interest and X = day on trial after 35 d of adaptation.

³Daily gains were calculated as the slope of the regression equation, where Y = variable of interest and X = day on trial after 35 d of adaptation.

⁴P-value associated with the treatment difference between the intercept or daily gain coefficients.

Growth

Heifer growth was monitored weekly to determine potential differences between treatments. Results for initial measurements and daily gains are presented in Table 2. These results indicate that maintaining the rate of weight gain by controlling access to feed was successful, because ADG between groups were not different (0.828 HF vs. 0.827 HC; SE $\pm$ 0.010 kg/d; $P > 0.94$). Average DMI required to obtain these levels of gain were 5.96 HF and 5.32 HC kg/d (SE $\pm$ 0.12; $P < 0.001$), and the associated FE (kg of ADG/kg of DMI) was 0.142 HF and 0.156 HC (SE $\pm$ 0.003; $P < 0.002$) for the experimental growth period.

Heifers in this trial had, on average, greater withers height and body length per unit of BW than the upper ranges of size recommended by Hoffman (1997). Although only weight gain could be controlled, growth of all structural characteristics, except for paunch girth, was unaffected by dietary regimen, expressed either as daily gains (cm/d) or as allometric expressions (Tables

2 and 3, and Figure 1). The near constancy in structural size and gains indicates that, under the conditions of the current experiment, BW was the major factor influencing these variables and that differences in growth attributable to dietary treatment were minimal.

Interestingly, initial paunch girth and growth were affected by diet forage level (Figure 1C). Initial paunch girth was greater for heifers fed HF, but paunch girth gain was greater for heifers fed HC in that these heifers eventually surpassed heifers fed HF. The initial value corresponded to the beginning of the feeding trial, after the 35-d adaptation, which was included to allow animals to adapt to the chemical composition of the ration as well as to the amount and physical nature of the diet. Previous experiments related to gut fill differences arising from diet digestibility support the results of this study: that a greater paunch girth arising from greater gut volume would be required to allow for digestion of bulkier, more fibrous material (Bailey, 1986; Scollan et al., 2003). Presumably, this difference in gut fill would remain as animals grew; results from Bailey (1986) show a consistent and significant increase in digesta weights for steers fed HF vs. HC over all BW from 100 to 500 kg. Williams et al. (1992) proposed a method for calculating gut fill based on forage NDF concentration, forage type (silage or hay), concentrate level, and full BW. If these equations can be applied with validity to heifers in this experiment, gut fill at the completion of the experiment would be 59.0 HF vs. 30.7 HC kg (SE $\pm$ 0.5; $P < 0.001$). From this it could be inferred that HF heifers would require a considerably greater gut volume to accommodate the greater mass. If the HF heifers did in fact have a greater gut fill than HC heifers, and because ADG and structural characteristics were not different between groups, then differences observed between diets in paunch girth growth could arise from a differing composition of the paunch contents.

Table 3. Allometric growth responses relating structural growth measurements to BW (kg) for Holstein heifers fed a high-forage (HF) or high-concentrate (HC) diet for similar ADG before puberty¹

Item, cm	HF	HC	RMSE ²	P ³
Withers height	$26.2 \times \text{BW}^{0.27}$	$26.3 \times \text{BW}^{0.27}$	1.253	0.912
Heart girth	$15.2 \times \text{BW}^{0.41}$	$14.5 \times \text{BW}^{0.42}$	2.250	0.455
Paunch girth	$32.4 \times \text{BW}^{0.31}$	$19.7 \times \text{BW}^{0.41}$	3.586	<0.001
Length	$20.2 \times \text{BW}^{0.34}$	$20.1 \times \text{BW}^{0.34}$	2.548	0.801
Hip width	$2.5 \times \text{BW}^{0.48}$	$2.4 \times \text{BW}^{0.49}$	0.734	0.193

¹n = 21 for HF and n = 20 for HC, those that completed the feeding trial. The model included heifer as a random effect.

²Root mean square error.

³P-value associated with the treatment difference between allometric equations.

Figure 1. Relationships between withers height (A), heart girth (B), paunch girth (C), length (D), and hip width (E) growth measurements and BW for Holstein heifers fed a high-forage (HF) or high-concentrate (HC) diet for similar ADG before puberty ($n = 21$ for HF and $n = 20$ for HC, those that completed the feeding trial). High-forage values are represented by $\blacklozenge$ and the fitted line by —; HC values are represented by $\blacksquare$ and the fitted line by - - -. Y-values are adjusted for the random effect of heifer.

Although body composition was not measured, this situation could possibly result from a replacement of gut contents and tissue weight with visceral fat tissue weight. Two serial slaughter experiments, however, failed to detect any differences in visceral tissue fat accretion in animals fed HF and HC diets for similar ME intakes, even though ADG was greater for HC-fed animals in both experiments (Coleman et al., 1995; Kim et al., 2003). The precise cause of the greater rate of paunch girth gain for heifers fed HC is unknown from the results of the current experiment; however, knowledge of the composition of the visceral tissues and gut fill would be of great utility in practical feeding systems in which HC diets are fed for controlled growth.

Puberty

Results related to characteristics of heifers at attainment of puberty are presented in Table 4. Heifers receiving HC were younger and lighter at puberty than were those fed HF, although these results were not significant. Results from this experiment compare closely with other recently published results concerning BW of Holstein heifers at puberty. Capuco et al. (1995) reported BW at puberty lower than the results of this experiment; several other experiments reported higher BW (Radcliff et al., 1997; Lammers et al., 1999), and others were similar (Meyer et al., 2006). The weighted average of BW at puberty of the 221 heifers from these published experiments is 291 kg compared with an average of 290 kg in the current experiment.

The experimental ADG prior to puberty (0.837 HF vs. 0.837 HC; $SE \pm 0.009$ kg/d; $P > 0.96$) was unintentionally greater than the ADG observed during the entire feeding period for both treatments. This situation may have resulted from reduced FE for both groups after puberty; FE fell by 0.023 kg/kg for HF and 0.031 kg/kg for HC ($SE \pm 0.007$; $P > 0.48$). In an attempt to determine whether the shift in FE did indeed occur around puberty, a piecewise linear regression was conducted in which the BW at which the shift occurred was fitted objectively. Results of this analysis indicated that the BW at which the shift in efficiency occurred was correlated with puberty BW in heifers fed HF ($r = 0.746$; 95% confidence limits: $0.557, 0.934$). However, heifers fed HC had no correlation between these 2 variables ($r = 0.187$; 95% confidence limits: $-0.236, 0.610$). Whether differences in the strength of these relationships are the result of an underlying physiological difference between heifers fed different diets could not be determined in this experiment.

Lifetime and experimental ADG until puberty did not differ between diets. The experimental period began after the calthood phase, in which nutritional alter-

Table 4. Reproduction measurements taken during the rearing period for Holstein heifers fed a high-forage (HF) or high-concentrate (HC) diet for similar ADG before puberty¹

Item	HF	HC	SE	P ²
Age at puberty, d	333	320	6	0.166
BW at puberty, kg	293	287	7	0.590
Lifetime ADG to puberty, kg/d	0.761	0.771	0.012	0.573
Experimental ADG to puberty, kg/d	0.837	0.837	0.009	0.967
Conception rate, %	83	75	7	0.423

¹n = 17 for HF and HC, those heifers that completed 150 d of lactation.

²P-value associated with the treatment difference.

ations can influence mammary development (Brown et al., 2005), and treatment rations were fed until after puberty had been confirmed. Thus, treatments were delivered during the physiological stage associated with prepubertal allometric mammary growth (Sinha and Tucker, 1969), and ADG were not different between dietary groups during this stage. This result is consistent with our objective of not only keeping ADG similar between groups, but also maintaining it at an optimal level that has been shown to allow maximal levels of production (Zanton and Heinrichs, 2005).

Lactation

After completing the experimental feeding period, all heifers were managed as a group in accordance with protocols of the Penn State dairy. Although the number of animals is too small for inferences about reproduction to be powerful, conception rate was not affected by treatment ($P > 0.42$) and occurred at a time that allowed heifers to calve at an average age of 23.4 mo (Table 5; $P > 0.50$). Average BW at calving (BWC) was 548 kg and was not different between treatments (Table 5, $P > 0.16$). These averages are within the currently recommended range; however, average BWC for heifers fed HF equaled the lower limit of the range recommended for BWC (Hoffman, 1997).

Table 5. Production values through 150 DIM for Holstein heifers fed a high-forage (HF) or high-concentrate (HC) diet for similar ADG before puberty¹

Item	HF	HC	SE	P ²
Age at first calving, mo	23.3	23.5	0.2	0.511
BW after calving, ³ kg	536	560	11	0.166
Nadir BW, kg	493	483	9	0.478
BW loss to nadir, kg	43	76	8	0.011
Milk production, kg/d	31.70	34.70	1.46	0.134
Peak milk, kg/d	37.73	42.51	1.80	0.081

¹n = 17 for HF and HC, those heifers that completed 150 d of lactation. Production values were based on weekly averages from daily measurements.

²P-value associated with the treatment difference.

³Mean BW from wk 1 after calving.

Although not statistically different, heifers fed HF before puberty were 24 kg lighter at calving than heifers fed HC. Because BW at the end of the feeding experiment was not different ($P > 0.80$), heifers fed HC had a numerically greater ADG after puberty than those fed HF. From previous research it can be inferred that postpubertal period ADG has an insignificant effect on mammary development (Sejrsen et al., 1982) and milk production (Grummer et al., 1995; Hoffman et al., 1996). It was stated previously that predicted gut fill was greater at the conclusion of the experiment for heifers fed HF than HC, resulting in a 27-kg advantage in empty BW (EBW) for heifers fed HC. If the proportion of live weight (LW) that was digesta had become equivalent by the time of calving, then the difference in LW at calving could be largely due to differences in EBW produced during the experimental period, with the additional gain being that of digesta. By this reasoning, however, predicted EBW ADG during the experimental period was greater for heifers fed HC (0.782 kg/d) than for heifers fed HF (0.688 kg/d; $P < 0.001$).

Current recommendations for ADG prior to puberty are related only to LW ADG (Hoffman, 1997; Sejrsen et al., 2000; Zanton and Heinrichs, 2005). How the EBW ADG in this trial fits relative to that which would result in maximum first-lactation milk production is not known. From milk production results, it can be inferred that the level of accelerated prepubertal EBW gains predicted for heifers fed HC in this experiment did not translate into reduced milk production.

The results from the first 150 d of first lactation are shown in Tables 5 and 6 and in Figure 2. For most production values, heifers fed HC prior to puberty had an advantage, although this advantage was significant only for FCM and fat production ($P < 0.02$). Covariate analysis of BWC and BW loss to nadir were not significant for production results ($P > 0.30$) and are not included in results presented. The only significant covariate determined by regression analysis was total BW change over 150 DIM ($P < 0.01$ for all variables except protein production and fat concentration: $P > 0.10$). Including this covariate reduced the significance for FCM

Table 6. Projected 305-d mature equivalent production for Holstein heifers fed a high-forage (HF) or high-concentrate (HC) diet for similar ADG before puberty¹

Item	HF	HC	SE	P ²
Milk, kg	8,740	9,776	390	0.081
4% FCM, kg	8,343	9,681	368	0.020
Fat, kg	323	385	16	0.013
Protein, kg	271	294	10	0.144
Fat, %	3.71	3.95	0.11	0.138
Protein, %	3.12	3.02	0.04	0.118

¹n = 17 for HF and HC, those heifers that completed 150 d of lactation. Projected at a mean DIM of 154 d. Dairy Herd Improvement Association test day values measured at 2 consecutive milkings monthly.

²P-value associated with the treatment difference.

to $P < 0.086$ from 0.020 and for fat production to $P < 0.054$ from 0.013. In all cases in which covariates were included, heifers fed HC prior to puberty maintained a numerical advantage over heifers fed HF, although with less statistical significance.

The results of this trial concur in part with those previously comparing HC to HF diets when fed for controlled gains (Hof and Lenaers, 1984; Sejrsen and Foldager, 1992; Carson et al., 2000). In each of these trials, milk production was not different between heifers fed HC or HF during the rearing period, although in each case heifers fed HC produced numerically greater amounts of milk. The results of this trial, however, are the only ones in which significance was approached ($P < 0.081$) for milk production or achieved for FCM production.

CONCLUSIONS

From the results of this experiment, we conclude that feeding dairy heifers HC before puberty did not affect most structural growth characteristics and puberty attainment, and equaled or improved 150-d milk and component production compared with heifers fed HF for equal ADG. From the responses measured in this experiment, there seems to be little biological rationale opposing the use of HC rations for dairy heifers, provided that ADG is controlled and feed ingredients can be used to maintain a healthy rumen environment. Controlled feeding of an HC ration during the rearing period may allow for improved efficiency for dairy heifers while maintaining future productivity.

ACKNOWLEDGMENTS

This research was supported in part by USDA grant no. 2003-34281-13382. Sincere appreciation is extended to Maria Long for assistance with laboratory analysis and Coleen Jones for editorial support.

Figure 2. Body weight (A), BW change (B), and milk production response (C) profiles through 150 DIM for Holstein heifers fed a high-forage (HF) or high-concentrate (HC) diet for similar ADG before puberty (n = 17 for HF and HC, those heifers that completed 150 d of lactation). High-forage values are represented by $\diamond$ and —; HC values are represented by $\blacksquare$ and - - -; SE bars are shown for the treatment by week interaction. Production values are based on weekly averages from daily measurements made using the Afifarm system (S.A.E. Afikim, Kibbutz Afikim, Israel). A significant week effect was found for BW, BW change, and milk production ($P < 0.001$). The treatment effect was not significant for BW ($P > 0.20$), but the treatment by week interaction tended toward significance for BW ($P < 0.093$). There was a tendency for a treatment effect for BW change ($P < 0.066$), but the treatment by week interaction was not significant ($P > 0.10$) for BW change. Treatment and treatment by week interactions were not significant ($P > 0.100$) for milk production.

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